

STRUCTURAL VERIFICATION FOR GAS EXPERIMENTS

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ABSTRACT

The purpose of this paper is to assist the Get Away Special (GAS) experimenter in conducting a thorough structural verification of its experiment structural configuration, thus expediting the structural review/approval process and the safety process in general. Material selection for structural subsystems will be covered with an emphasis on fasteners (GSFC fastener integrity requirements) and primary support structures [Stress Corrosion Cracking requirements and National Space Transportation System (NSTS) requirements]. Different approaches to structural verifications (tests and analyses) will be outlined especially those stemming from lessons learned on load and fundamental frequency verification. In addition, fracture control will be covered for those payloads that utilize a door assembly or modify the containment provided by the standard GAS Experiment Mounting Plate (EMP). Structural hazard assessment and the preparation of structural hazard reports will be reviewed to form a summation of structural safety issues for inclusion in the safety data package.

INTRODUCTION

All GAS experimenters must conduct a structural verification of experiment support structures in accordance with National Aeronautics and Space Administration (NASA) requirements. The structural review/approval cycle is a mandatory step in the NSTS safety process and is required for GAS experiments to receive approval for flight on the Space Shuttle.

The unique scientific objectives and mission requirements of the specific experiments being conducted will determine the experiment primary support structure. After the design of the primary support structure has been established, the structure can be further developed depending on experiment subsystems. For instance, electronics, power, or fluid subsystems may be further contained within individual boxes. The experiment structure selection process is finalized by determining the materials with which to build the support structure as well as the fasteners that will mount and hold the structure together. The experiment structure must be ultimately designed to attach to NASA standard hardware and will be cantilevered from the NASA mounting surface with lateral support in the form of bumpers at the free end of the experiment structure.

Once the experiment support structure materials and design have been selected, the payload organization is required to verify that the structure can withstand the worst case loading and vibration requirements associated with the launch and landing of the Space Shuttle. Since most Space Shuttle payloads are required to verify structures by a combination of analysis and test, the GAS experimenter is fortunate to be able to verify compliance with NSTS structural requirements by analysis only. If so desired, the GAS experimenter may verify compliance by a combination of analysis and test.

MATERIALS SELECTION

Before the support structure is verified via analysis or test, the payload organization must select structural materials that are acceptable to NASA. Particular scrutiny is given to the primary load bearing structure and the structural fasteners.

Stress Corrosion Cracking (SCC)

One of the major concerns associated with materials selection for the primary support structure, fasteners, support brackets, and mounting hardware is Stress Corrosion Cracking (SCC). SCC is defined in MSFC-SPEC-522, Design Criteria for Controlling Stress Corrosion Cracking, as "the combined action of sustained tensile stress and corrosion to cause premature failure of materials." Certain materials are more susceptible to corrosion; and when these materials are subjected to corrosion inducing environments, cracking and subsequent failure under loading will occur at lower stress levels than normal for the material. The corrosion leading to failure in many cases is not necessarily severe enough to be visible to the human eye. However, especially in the corrosive seacoast environment of the Kennedy Space Center (where GAS payloads reside for at least three months before flight on the Space Shuttle), SCC must be addressed since structures will be subjected to additive tensile stresses from assembly, transportation, storage and ultimately, the Space Shuttle mission. The Marshall Space Flight Center has conducted tests on numerous structural materials under a simulated seacoast environment that is similar in both temperature and chemical exposure to the environment that a GAS payload will experience. Table 1 of MSFC-SPEC-522 lists the alloys that exhibit a high resistance to SCC and these alloys are acceptable for all structural applications in GAS payloads. GAS payloads should select structural materials from Table 1 of MSFC-SPEC-522.

Materials listed in Table 1 of MSFC-SPEC-522 are in full compliance with NSTS 1700.7, Safety Policy and Requirements for Payloads Using the Space Transportation System, requirements concerning stress corrosion. Protective coatings such as electroplating, anodizing, alodining, iriditing, and chemical conversion coatings applied to alloys with high resistance to SCC have no affect upon the stress corrosion rating of the alloy. Surface treatments such as carburizing and nitriding may adversely affect the stress corrosion rating. Any alloy surface treatment must be identified when the experiment materials list is submitted. Use of dissimilar metals that are not protectively coated should be avoided especially in reinforcement applications (for example, brackets or braces), because the dissimilar metals may form electrical couples which could lead to galvanic corrosion.

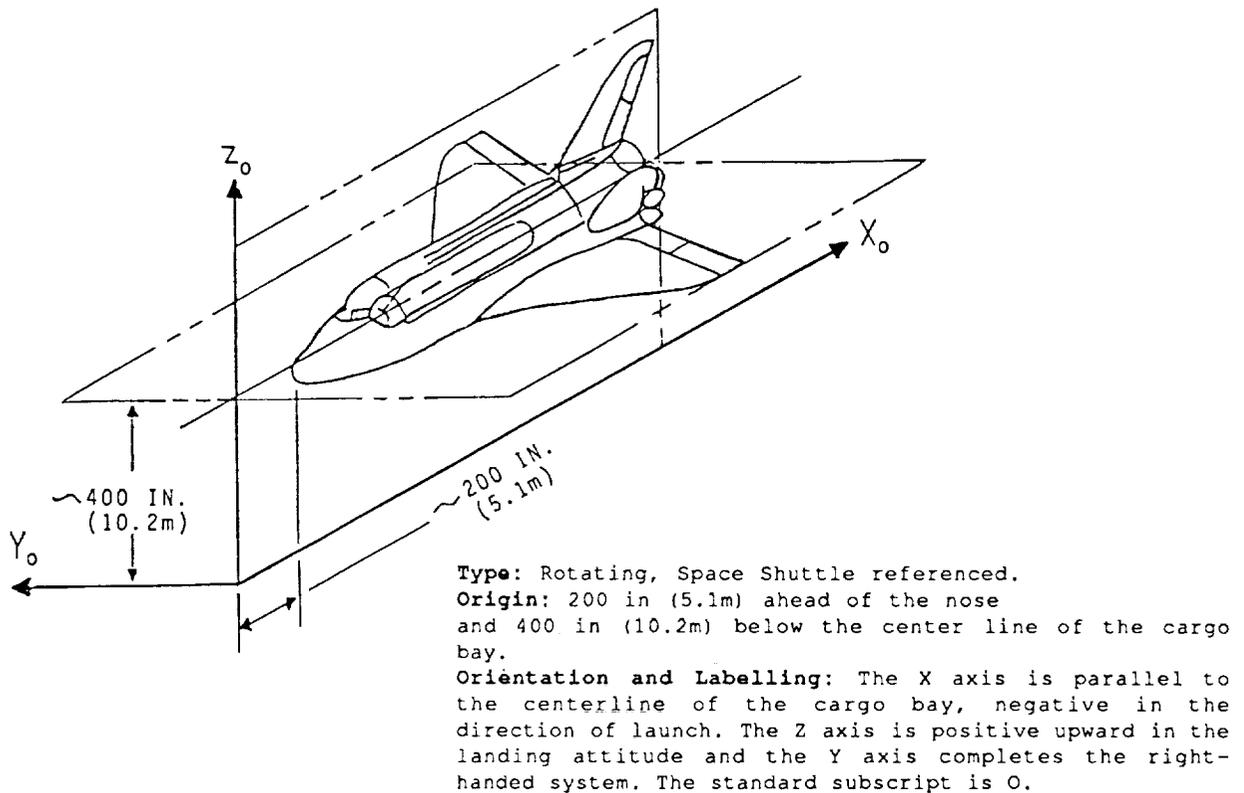
Fasteners

Fastener materials selection for GAS payloads is dependent upon the GAS canister configuration selected by the payload organization. For GAS payloads that utilize an opening door assembly or for other payloads that require fracture control due to deviance from the standard sealed GAS canister configuration, compliance with the Goddard Space Flight Center (GSFC) Fastener Integrity Requirements (GSFC Document #S-313-100) is mandatory. This means that the payload organization must either select fasteners from the GSFC approved manufacturers list (Appendix I of GSFC S-313-100) or fasteners must be in accordance with GSFC S-313-100 which may mean conducting quality assurance screening tests and inspections as well as traceability. In addition, for GAS payloads that require fracture control, the fasteners must employ positive retention such as lock wire or lock nuts. For GAS payloads that remain in the standard sealed GAS canister configuration, it is preferred but not required that the payload organization select fasteners from the GSFC approved manufacturers list.

STRUCTURAL VERIFICATION

The basic requirements for all GAS experiment support structures are as follows:

- 1) The structure must withstand flight limit loads of 10 g's in the X, Y, and Z axes with an ultimate factor of safety of 2.0 when verified by analysis only or an ultimate factor of safety of 1.5 when verified by test to a yield factor of safety of 1.25. The structure must also exhibit positive margins of safety under these loads. The loads must be combined using the X, Y, and Z loads in the worst case loading conditions (this means combining compression, tension, bending, and shear stresses). The Space Shuttle coordinate system (Figure 1) is used for defining the load direction.
- 2) The fundamental frequency of the experiment support structure about any axis must be greater than or equal to 35 Hz. This can be verified by analysis or test.



From the GAS Safety Manual

FIGURE 1 - Space Shuttle Coordinate System

Additional structural requirements are imposed on GAS payloads that utilize an opening door assembly or compromise the sealed nature of the GAS canister by modifying the containment provided by the GAS EMP (for example, payloads that attach structure to the surface of the EMP external to the GAS canister). These payloads must comply with the fracture control requirements of GSFC # 731-0005-83, General Fracture Control Plan for Payloads Using the Space Transportation System.

Verification of Basic Requirements

GAS experimenters have the option of verifying structural integrity through analysis only. Of course, the GAS experimenter may also test as long as the test results are supported by an analysis. The two basic loading and vibration requirements listed previously can thoroughly be verified using classical techniques or finite element analysis. However, conducting a series of verification tests is sometimes preferred due to the level of confidence and accuracy that it provides to the GAS experimenter. Since the structural analysis or test report is reviewed separately from the safety data package, the structural analysis/test report should not be included within the safety data package. The structural analysis/test report should be forwarded to GSFC as an independent document.

Structural Analysis

GAS experimenters are usually subjected to multiple iterations during the structural review process. The initial structural analysis is often reviewed and disapproved with a number of comments that must be answered before the structures will receive approval. Verification of the basic requirements by analysis is not always easy, and the following guidelines are provided to expedite the structural review/approval process:

- a) Description of Structure - The experimenter should introduce the structural analysis document by including a detailed description of the experiment support structure. This description should reference applicable figures that clearly illustrate mounting interface with NASA hardware, primary load bearing support structure, distribution and mounting of individual experiment components as well as lateral support bumpers. A table indicating the weight breakdown of experiment components and the location of the components on the primary support structure should be included. Components should be grouped in correlation to their location on the primary support structure (for example, all components attached to an intermediate shelf would be grouped together).
- b) Material Properties - Material properties for the experiment support structure and fasteners, such as the allowable loads and modulus of elasticity, that are used in the structural calculations should be listed in tabular form. These values should be obtained from MIL-HDBK-5.
- c) Assumptions - The experimenter should establish assumptions that are used in the structural analysis and calculations (for example, the assumption that loadings result from the specified flight limit loads multiplied by the applicable factor of safety and associated masses or the assumption that thermal effects on the loading are negligible). The experimenter must be careful when modelling the payload for structural calculations. Sometimes, the assumptions of the structural model are not accurate and the experimenter will oversimplify the model. The experimenter must clearly and appropriately model the structure so that the calculations are not only accurate but easy to follow.
- d) Abbreviations - An abbreviations list should precede the structural calculations.
- e) Primary Load Bearing Structure - The stress analysis and fundamental frequency analysis should address all main components of the experiment structure that bear loads (for example, experiment structure that mounts to the GAS EMP, experiment shelves-top, bottom and intermediate, support struts, and side walls), because experimenters often neglect to analyze key load bearing components of the experiment support structure.

f) Margins of Safety - All primary structural parts and associated attachment fasteners as well as the attachment fasteners for components that weigh 5 pounds or more must be analyzed in detail for critical stresses and must exhibit positive margins of safety. The margins of safety should be based on the interactive method that considers the combined effects of tension and shear stresses from loads applied simultaneously. This interactive relation is given as follows:

$$\text{Margin of Safety, M.S.} = [1/(R_t^2 + R_s^2)^{1/2}] - 1$$

where, R_t = Tensile load (or stress)/Allowable tensile load (or stress)

R_s = Shear load (or stress)/Allowable shear load (or stress)

Any type of buckling analysis (taking into account pre-loads as well as inertial loads) for tubes or tube spacers and crippling strength analysis for struts should include calculations showing positive margins of safety.

g) Fasteners - When analyzing fasteners, the assumption that fastener shear force is reacted by friction is unacceptable. Shear loads must be reacted by bolts or shear pins; however, bolt threads or inserts should not be subjected to shear loads. The combined forces used in fastener analysis to determine worst case loading must take into account the effect of combining the bolt reactions. This means the loads applied to the fastener and the moments (for example, overturning moments and twisting moments due to an eccentricity of the component mounted) that result and cause additional bolt tension and shear loads must be considered in the calculations. Bearing stresses and combined local bending stresses should be examined in mounting flanges and brackets.

h) Fundamental Frequency - GAS payload structures that utilize a set of plates or shelves simply supported by struts with any number of intermediate plates can often be modelled for fundamental frequency analysis. The plates and support struts can basically be modelled as beams with equivalent loading based on the mass from the mounting of experiment components. The fundamental frequency can then be calculated by determining the properties of the modelled beams by the beam support fixtures and then using classical beam equations. The other option is to use finite element modelling with a frequency dynamics run. Once again, the experimenter must be careful not to oversimplify the structural model. Accurate assumptions and accurate beam modelling are essential to analyze the experiment support structure's fundamental frequency.

i) Finite Element Analysis - If the experimenter chooses the finite element method over classical techniques, the finite element model must be a detailed math model (analytically simulating the mass and stiffness) with a level of fidelity that accurately approximates all components of the experiment support structure. The location and values of the stresses for finite element analysis must be identified. An identification of the critical parts and components in which the stresses occur should be included as well. The mesh size used in the analysis must be appropriate to the type of run used (for example, a dynamic run or stress run). The finite element analysis should show deformed plots for both the dynamic and static load cases. This is to verify that the deformations are consistent with applied loads. The analysis should be detailed in the description of the application of accelerated loads. The acceleration loads in the three axes should encompass a worst case combination. The weight breakdown used in the analysis should be equivalent to that of all experiment components. A frequency dynamics run can be used to verify the fundamental frequency. The experimenter must clearly present the methods and assumptions used in the finite element analysis along with a clear description of the results that show structural compliance.

j) Composites - Some GAS payloads use a fiberglass/epoxy or other composite material for intermediate plates or trays to house experiments. It is desirable to avoid placing composite structural members in the primary load path. When composites are used, the experimenter must examine the connection to the primary load path and make sure that the shear strength of the composite material is sufficient to accommodate the required flight loads. The composite must not delaminate under these conditions.

k) Welds - All welds used in structural applications must be verified in accordance with MIL-STD-2219.

l) Conclusions - The experimenter should organize structural analysis results and present them in a conclusion section. Margins of safety for fasteners and the various components of the experiment support structure should be listed in tabular form. The experimenter should briefly and clearly summarize how the GAS structural requirements for loading and fundamental frequency have been met through analysis of the components of the experiment support structure.

Structural Tests

Some GAS experimenters elect to verify the experiment support structure through testing. GAS experimenters prefer tests in some cases, because tests provide more concrete results and more adequately exhibit actual experiment support structure reactions to flight loads. Before testing, structural analysis is still required to factors of safety of 1.25 for yield and 1.5 for ultimate over the flight limit loads. Structural tests are then conducted to visually verify that the structure can actually sustain the specified flight loading and still survive. The GAS experimenter should provide a description of the test set-up, test procedures followed, plots or other test results, and a summation of the test results that clearly show verification of the structural flight requirements. A number of structural tests are outlined below:

a) Static Loads Test - The static loads test is sometimes referred to as a "pull test" and consists of loading or pulling the structure to 1.25 times the flight limit loads. The experimenter can monitor the experiment support structure response using strain gages or other methods. The static test results are then correlated to determine if the stress and strain match those predicted by analysis.

b) Sine Burst Test - The sine burst test is a low frequency (< 20 Hz) sine test for 5 cycles at 100% of the test loads. The test load that should be applied is 17.7 g's in each of the three axes. This test load includes the required factor of safety (1.5) for the test. Again, the results should match the predicted values determined by analysis.

c) Sine Sweep Test - The sine sweep test is used to verify the experiment structure fundamental frequency. A harmonic vibration can be created by a vibration table or other method, and the vibration should be forced at the 1/4 g, 1/2 g, or 1 g level. A sine function vibration sweep from 20 Hz to 200 Hz is applied and the associated test result plots are used to determine the resonant frequency.

d) Random Vibration Test - The random vibration test verifies workmanship and results are not acceptable for structural verification. The GAS experimenter is not required to conduct a random vibration test but may desire to conduct such a test for confidence purposes. Appropriate levels may be found in the GAS Experimenter Handbook.

Fracture Control

Fracture control in accordance with GSFC 731-0005-83 is required for all GAS payloads that utilize a door assembly or modify the containment provided by the GAS EMP in the standard sealed GAS canister configuration. The GAS experimenter is responsible for exhibiting compliance with these requirements through test or analysis. Fracture control is required to prevent cracks, flaws, or other defects from initiating in the structure and propagating to experiment support structure failure. General requirements for such GAS payloads are covered below.

Assumptions

All structural components are assumed to have preexisting flaws in the most critical locations and orientations. Non-Destructive Evaluation (NDE) establishes the upper bound for the size of the preexisting flaw. Fracture mechanics determines flaw growth and critical flaw size. A scatter factor of 4 is used in all fracture mechanics analyses to account for material properties and uncertainties. The eventual failure and separation of any part $\geq 1/4$ lb is construed as a catastrophic hazard to the Space Shuttle or crew.

Classifications

Every part of a GAS experiment will fall into one of the following 4 categories:

- 1) Low Released Mass - part has a mass $< 1/4$ pound.
- 2) Contained - all parts or fragments, of parts weighing $\geq 1/4$ pound are analyzed as being prevented by some barrier from entering the Space Shuttle cargo bay.
- 3) Fail-Safe - due to structural redundancy, the structure that remains after any single failure can withstand the redistributed loads.
- 4) Safe-Life - the largest undetected flaw that is assumed to preexist in a part will not grow to failure under the cyclic and sustained loads encountered in four complete mission lifetimes (including fabrication, testing, transportation, lift-off, ascent, on-orbit, descent, landing, and post-landing loads). Flaw growth software is often used to establish a part as safe-life.

In most cases, GAS payload parts will fall into one of the first 3 classifications and therefore are non-fracture critical. The GAS experimenter is required to assess all payload parts by these classifications and provide the analysis or test to substantiate the classification. For more specific and individually applicable requirements, the GAS experimenter should reference GSFC 731-0005-83.

SAFETY ASSESSMENT

The structural safety assessment for inclusion in the safety data package varies depending on the method of structural verification.

For verification by analysis the hazard assessment section should simply read, "To ensure sufficient structural stability, the experiment support structure was designed and built to withstand appropriate flight loads to an ultimate factor of safety of 2.0, and the fundamental frequency about any axis is ≥ 35 Hz." The hazard control verification should read, "Structural analysis has indicated compliance with the appropriate flight limit loads and an ultimate factor of safety of 2.0. All margins of safety are positive. Analysis indicates that the fundamental frequency about any axis is greater than or equal to 35 Hz."

For verification by test the hazard assessment should simply read, "To ensure sufficient structural stability, the experiment support structure was designed and built to withstand appropriate flight loads with an ultimate factor of safety of 1.5, and the fundamental frequency about any axis is ≥ 35 Hz." The hazard control verification section should read, "Structural tests have indicated compliance with the appropriate flight limit loads to yield factor of safety of 1.25 and that the fundamental frequency about any axis is greater than or equal to 35 Hz. Supporting analysis has shown an ultimate factor of safety of 1.5. All margins of safety are positive."

For GAS payloads requiring fracture control, an additional statement should be added to the hazard assessment and hazard control verification section indicating that the experiment support structure has been analyzed (or tested, if applicable) in accordance with GSFC 731-0005-83. Also, it should be indicated that structural fasteners have been selected in accordance with the GSFC Document #S-313-100 and employ positive retention.

To complete the structural safety assessment, a hazard report must be prepared for the structural failure hazard. Two generic structural hazard (Figures 2 and 3) reports are included for general reference and tailoring to specific experiment structural design and verification methods.

PAYLOAD HAZARD REPORT		No.
PAYLOAD		PHASE
SUBSYSTEM Structures	HAZARD GROUP Collision	DATE
HAZARD TITLE Failure of Experiment Support Structure		
APPLICABLE SAFETY REQUIREMENTS NSTS 1700.7B 206 Failure Propagation 208.1 Structural Design 208.2 Emergency Landing Loads 208.3 Stress Corrosion		HAZARD CATEGORY X Catastrophic Critical
DESCRIPTION OF HAZARD During launch/landing operations, the experiment support structure fails resulting in release of the experiment inside the GAS canister.		
HAZARD CAUSES 1. Inadequate structural design for launch and landing environment. 2. Improper materials selection.		
HAZARD CONTROLS 1. (a) Fundamental frequency of experiment support structure about any axis ≥ 35 Hz. (b) Experiment support structure designed to an ultimate Factor of Safety of 2.0 (or 1.5 for verification by test) over appropriate flight limit loads with positive margins of safety. (c) GAS canister containment of the experiment in the event of experiment support structure failure. 2. Materials selected in accordance with stress corrosion requirements of MSFC-SPEC-522B.		
SAFETY VERIFICATION METHODS 1. (a) Sinusoidal vibration test or Vibration analysis. (b) Structural analysis or Test to yield factor of safety of 1.25. (c) GAS Canister Containment Analysis. Standard Sealed GAS Canister Assembly/Integration Procedure. 2. GSFC Materials Branch (Code 313) review.		
STATUS OF VERIFICATION 1. (a) Closed. Approved by GSFC (XX/XX/92). (b) Closed. Approved by GSFC (XX/XX/92). (c) Closed. GSFC Analysis GAS-CAN01-014 and Procedure GAS-CAN-08-011 to be performed at KSC and documented in the Verification Tracking Log (VTL). 2. Closed. GSFC Materials Branch approval (XX/XX/92).		
PHASE III APPROVALS	GAS P/L Manager	GAS Safety Officer
	GAS Project Manager	STS

FIGURE 2 - General Structural Hazard Report

PAYLOAD HAZARD REPORT		No.
PAYLOAD		PHASE
SUBSYSTEM Structures	HAZARD GROUP Collision	DATE
HAZARD TITLE Failure of Experiment Support Structure		
APPLICABLE SAFETY REQUIREMENTS NSTS 1700.7B: 206 Failure Propagation 208.1 Structural Design 208.2 Emergency Landing Loads 208.3 Stress Corrosion		HAZARD CATEGORY
		X Catastrophic
		Critical
DESCRIPTION OF HAZARD During launch/landing operations, the experiment support structure fails resulting in release of the experiment.		
HAZARD CAUSES 1. Inadequate structural design for launch and landing environment. 2. Defective material. 3. Defects or flaws assumed to be present in the experiment structure propagate to failure.		
HAZARD CONTROLS 1. (a) Fundamental frequency of experiment about any axis ≥ 35 Hz. (b) Experiment support structure designed to an ultimate Factor of Safety of 2.0 (or 1.5 for verification by test) over appropriate limit loads with positive margins of safety. 2. Materials selected in accordance with stress corrosion requirements of MSFC-SPEC-522B. 3. The structure was designed in accordance with GSFC 731-0005-83, Rev. B, General Fracture Control Plan for Payloads Using the STS. All payload elements are either low released mass, contained, or fail-safe; therefore non-fracture critical.		
SAFETY VERIFICATION METHODS 1. (a) Vibration Analysis or Vibration Test. (b) Structural analysis or Test to yield factor of safety of 1.25. 2. GSFC Materials Branch (Code 313) review. 3. Fracture Control Analysis or Test.		
STATUS OF VERIFICATION 1. (a) Closed. Approved by GSFC (XX/XX/92). (b) Closed. Approved by GSFC (XX/XX/92). 2. Closed. GSFC Materials Branch approval (XX/XX/92). 3. Closed. Approved by GSFC (XX/XX/92).		
PHASE III APPROVALS	GAS P/L Manager	GAS Safety Officer
	GAS Project Manager	STS

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FIGURE 3 - General Structural Hazard Report with Fracture Control